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(54) Spring-force measuring apparatus.

(57) The invention relates to an apparatus for measuring the spring force exerted upon a nuclear fuel rod when inserted through a fuel-assembly grid-cell having supporting spring means disposed therein.

The apparatus comprises a pair of bars (52, 54) which are hinged together and have end portions (62, 66) adapted for insertion into a grid cell (42). The bars are adjustable (86) to adapt the overall cross-sectional dimension of the insertable end portions (62, 66) to different fuel-rod diameters. The apparatus includes further a strain gauge (106) for sensing the progressively stronger force applied to the spring means (44) through operation of force generating means (80); a pair of normally closed contacts (108) connected to the spring gauge and set to open at the instance the spring means (44) yields to the increasing force being applied, and means (112) providing an indication of the level of force causing the spring means to yield.

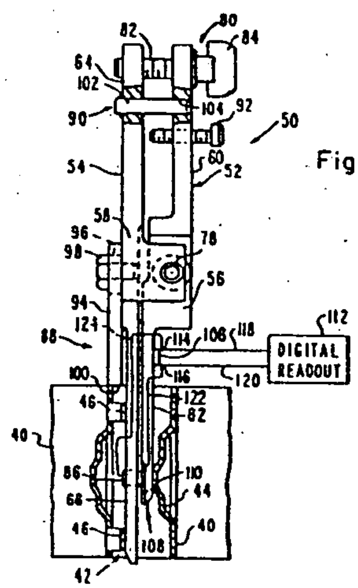

Fig. 7

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SPRING-FORCE MEASURING APPARATUS

The present invention relates generally to fuel assemblies for nuclear reactors and, more particularly, to an apparatus for measuring the spring force imposed on a fuel rod when disposed through a cell in the support grid of the fuel assembly.

In most nuclear reactors, the reactor core is composed of a large number of elongate fuel assemblies each including a plurality of fuel rods held in an organized array by grids which are spaced in the longitudinal direction of the fuel assembly and attached to elongate control-rod guide thimbles which likewise form part of the fuel assembly and have end nozzles secured to opposite end portions thereof.

As well known in the art, the grids of a fuel assembly are used to maintain a precise spacing between the fuel rods to prevent rod vibration, to provide lateral support for the fuel rods, and to frictionally hold the fuel rods against longitudinal movement thereof. Conventional grids usually are formed of straps interleaved egg-crate-like to define open cells each designed to receive a fuel rod or control-rod guide thimble. The cells intended to receive fuel rods are provided with spring means, usually in the form of resilient portions of the straps, and relatively rigid protrusions or dimples formed on strap portions opposite the respective spring means. The springs and dimples in each grid cell frictionally engage and

it requires separate measuring plugs with different dimensions to be made available for measuring spring forces associated with different fuel-rod diameters and different spacer geometries.

It is the principal object of the invention to provide a technique for measuring grid-spring forces in a manner which more nearly replicates real-life conditions in that it measures the forces actually experienced by fuel rods as they are supported in the cells of a grid and which permits such measurements to be conducted with relative ease, speed, and accuracy.

The invention accordingly resides in an apparatus for measuring the spring force imposed on a fuel rod when disposed through a cell in a support grid of the fuel assembly which cell contains spring means, comprising: (a) means for generating an increasing force at a first location external of the grid cell; (b) means for transmitting the increasing force from the first location and applying it to the spring means within the cell; and (c) means for measuring the level of the increasing force at the instance the application of the force causes deflection of the spring means.

More particularly, the invention provides a spring-force measuring apparatus comprising a pair of hinged bars adaptable to simulate fuel rods having different outside diameters, a strain gauge attached to one of the bars to sense the force applied to the spring means, and normally closed electrical contacts on the bars which separate or open at the instance the applied force becomes marginally greater than the spring reaction force causing the spring means to deflect. The apparatus electrically records the strain gauge reading at this instance and thus provides a determination of the spring force for the preselected fuel rod outside diameter. By repeating the procedure for different preset dimensions of the pair of bars of the apparatus, the spring rate of the spring/dimple cell system in the grid can be determined. In such manner,

rapid readout of forces is obtained with minimum apparatus setup requirements, and thus individual grid cells can be characterized with repeatability, speed and accuracy not attainable with conventional techniques.

A preferred embodiment of the invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

Fig. 1 is an elevational view, partly in section, of a nuclear fuel assembly having fuel rod support grids in conjunction with which the spring-force measuring apparatus embodying the invention can be employed;

Fig. 2 is an enlarged fragmentary top plan view of one of the fuel rod support grids of the fuel assembly of Fig. 1, showing the springs and dimples disposed within the grid cells and showing one of cells with a fuel rod extending therethrough;

Fig. 3 is an enlarged fragmentary sectional view taken along line 3-3 of Fig. 2;

Fig. 4 is an enlarged fragmentary sectional view similar to that of Fig. 3 but taken along line 4-4 of Fig. 2;

Fig. 5 is a side elevational view of the spring-force measuring apparatus embodying the invention;

Fig. 6 is a top plan view of the spring-force measuring apparatus of Fig. 5; and

Fig. 7 is another side elevation view showing the spring-force measuring apparatus inserted into one of the grid cells for the purpose of taking a spring-force measurement therein.

In the following description, like reference characters designate like or corresponding parts throughout the several views, and terms such as "forward", "rearward", "left", "right", "upwardly", "downwardly", and the like, are employed as words of convenience not to be construed as limiting terms.

Referring now to the drawings, and particularly to Fig. 1, the fuel assembly illustrated therein in

vertically foreshortened form and generally designated with reference numeral 10 basically comprises a lower end structure or bottom nozzle 12 for supporting the assembly on the lower core plate (not shown) in the core region of a reactor (not shown), a plurality of guide tubes or thimbles 14 extending longitudinally upward from the bottom nozzle 12, a plurality of transverse grids 16 axially spaced along the fuel assembly, an organized array of elongate fuel rods 18 transversely spaced and supported by the grids 16, an instrumentation tube 20 located in the center of the assembly, and an upper end structure or top nozzle 22 attached to the upper ends of the guide thimbles 14. The fuel assembly 10 forms an integral unit capable of being conventionally handled without damage to its parts.

As mentioned above, the fuel rods 18 in the array thereof in the assembly 10 are held in spaced relationship with one another by the grids 16 spaced along the fuel assembly length. Each fuel rod 18 contains nuclear fuel pellets 24 and has its opposite ends hermetically sealed by means of end plugs 26, 28. A plenum spring 30 between the upper end plug 26 and the pellets 24 maintains the latter firmly stacked. A liquid moderator/coolant, such as water, or water containing boron, is pumped upward through the fuel assemblies of the core, when in operation, in order to extract heat generated therein for the production of useful work.

The fission process is controlled by means of control rods 32 reciprocally movable in guide thimbles 14 at predetermined locations within the fuel assembly 10. For this purpose, the top nozzle 22 includes a rod cluster control mechanism 34 having an internally threaded cylindrical member 36 with a plurality of radially extending flukes or arms 38, each of which has a control rod 32 connected thereto.

<u>Grid Cell Spring Force Measurement Apparatus</u>

For maintaining the precise spacing between the fuel rods 18 and holding the latter against lateral and

longitudinal movement thereof, the grids 16 are conventionally designed to impose on each fuel rod 18 spring forces directed radially inward toward the longitudinal axis of the rod. Referring to Figs. 2 to 4, it is seen therefrom that each of the grids 16 comprises a multiplicity of inner straps 40 interleaved in an egg-crate-like manner to form open-end cells, as indicated at 42, a majority of which is designed to receive fuel rods 18 (for the purpose of clarity, only one cell 42 is shown in Fig. 2 with a fuel rod 18 disposed therein), and a minority of which is designed to receive control-rod guide thimbles 14.

The cells 42 of each grid 16 which accept and support the fuel rods 18 at a given axial location therealong typically use relatively resilient springs 44 and relatively rigid protrusions or dimples 46 formed into the metal of the interleaved inner straps 40 to generate the spring forces needed to hold the fuel rods therein. Also, the inner straps 40 are generally flexible such that they bow somewhat when the fuel rods 18 are disposed through the grid cells 42. In the illustrated embodiment, there are two springs 44 on two adjacent sides of each cell 42 containing a fuel rod 18 and two dimples 46 on each of two adjacent sides of the cell facing each spring. The springs 44 and dimples 46 of each grid cell 42 frictionally engage or contact the respective fuel rod 18 extending through th cell. Additionally, outer straps 48 are attached together and peripherally enclose the grid inner straps 40 to impart strength and rigidity to the grid 16. Thus, the actual spring force imposed on a given fuel rod 18 results from interaction with one another of the resilient springs 44, rigid dimples 46 and flexible interleaved straps 40 comprising the cell 42 which receives the fuel rod. In order to properly characterize the holding capability of an individual grid 16, it is this spring force that must be measured.

Turning finally to Figs. 5 to 7, for measuring the spring force, resulting from the combined action of the

system of resilient springs 44, rigid dimples 46 and flexible interleaved grid straps 40, imposed on a given fuel rod 18 when disposed through one cell 42 in one of the support grids 16 of the fuel assembly 19, the present invention provides a grid cell force measuring apparatus, generally designated 50. The measuring apparatus 50 includes a pair of front and rear elongate members 52, 54 having respective mid-sections 56, 58 and respective upper and lower end portions 60, 62 and 64, 66 extending in opposite directions from the respective mid-sections 56, 58. The members 52, 54 are pivotally connected together at their mid-sections 56, 58 such that as the upper end portions 60, 64 of the members, being juxtaposed in spaced apart relation to one another, are moved toward and away from each other, the lower end portions 62, 66 of the members, also being juxtaposed in spaced apart relation to one another, are moved away from and toward each other.

More particularly, the elongate members 52, 54 of the measuring apparatus 50 take the form of a pair of front and rear bars. The upper and lower end portions 64, 66 of the rear bar 54 extend in opposite directions from the mid-section 58 thereof and in generally linear alignment with one another, whereas the upper and lower end portions 60, 62 of the front bar 52 extend in opposite directions from the mid-section 56 thereof but in a transversely offset relationship. Due to such offset relationship, the upper end portion 60 of the front bar 52 is spaced farther or remote from the upper end portion 64 of the rear bar 54 while the lower end portion 62 of the front bar 52 is spaced closer or adjacent to the lower end portion 66 of the rear bar 54. Additionally, a pair of transversely spaced tabs 68, 70 are attached to the rear bar 54 at its mid-section 58 and extend generally parallel to one another and outwardly from a side thereof facing the front bar 52. The tabs 68, 70 have respective aligned holes 72, 74 defined therethrough, whereas a hole 76 is defined through the mid-section 56 of the front bar 52. A pivot pin 78

extends through the aligned holes 72, 74 in the spaced tabs 68, 70 on the rear bar 54 and through the hole 76 in the front bar 52 so as to mount the front bar on the tabs for pivotal movement relative to the rear bar.

Further, the measuring apparatus 50 includes force generating means, generally designated 80, coupling the upper end portions 60, 64 of the front and rear elongate bars 52, 54 together and being operable to apply a progressively increasing force so as to draw the upper end portions toward one another and thereby, via the pivotal connection of the bars, push the lower end portions 62, 66 apart from one another. In particular, the force generating means 80 includes a shaft 82 rotatably connected to one of the upper end portions 60, 64 of the bars 52, 54, such as the upper end portion 60 of the front bar 52, and threadably connected to the other thereof, such as the upper end portion 64 of the rear bar 54. A knob 84 is attached to an end of the shaft 82 disposed adjacent the front bar 52 for facilitating rotation of the shaft through manual turning of the knob in either of two opposite directions in order to move the upper end portions 60, 64 of the elongate bars 52, 54 toward and away from each other. Thus, the rotatable shaft 82 and knob 84 of the force generating means 80 are used to generate an increasing force at a first location along the elongate bars 52, 54 which will be external of the given one grid cell 42 when the lower end portions 62, 66 of the bars 52, 54 are inserted in the cell to the position seen in Fig. 7 for carrying out the measuring procedure. The elongate bars then serve as means for transmitting that increasing force from the first location therealong and applying the force at a second location displaced from the first location and internal of the one grid cell 42.

The elongate bars 52, 54 of the measuring apparatus 50 can be adjusted to simulate fuel rods of various diameters. Toward this end, means in the form of a set screw 86 is attached to the lower end portion 62 or 66 of

the one of the elongate bars 52, 54 and can be adjusted to preset the displacement between the lower end portions of the bars. Specifically, by rotating the set screw 86, which in the illustrated embodiment is threadably attached to the lower end portion 66 of the rear bar 54, and by simultaneously adjusting the shaft 82 on the upper end portion 60 of the front bar 52, the set screw 86 is operable to coact with the lower end portion 62 of the front bar 52 to preset a minimum displacement between the bars at the respective lower end portions thereof and thereby a minimum combined cross-sectional dimension of the bars at their lower end portions. Then, when the lower end portions of the bars are inserted into a given one grid cell 42, such as seen in Fig. 7, they will simulate a fuel rod 18 disposed through the cell having a predetermined outside diameter.

Other features of the measuring apparatus 50 comprise an adjustable stop 88, guide means 90 and limit means 92. The adjustable stop 88 includes a strip 94 having an elongate slot 96 and being attached to one of the bars, such as the mid-section 58 of the rear bar 54 along the rearwardly facing side thereof, by a bolt 98 inserted through the slot. The strip 94 extends downwardly a short distance and has a lower terminal end 100 for engaging the top of a grid strap 40, as seen in Fig. 7, to provide correct positioning of the lower end portions 62, 66 of the bars 52, 54 in the one grid cell 42 for applying the increasing force to one of the springs 44 in the cell. The position of the terminal end 100 of the strip 94 can be vertically adjusted by untightening the bolt 98 and then sliding the strip 94 relative thereto.

The guide means 90, being coupled between the upper end portions 60, 64 of the front and rear bars 52, 54 to assist in maintaining alignment of the bars with one another as they are pivotally moved relative to one another, includes a guide pin 102 and a guide bore 100. The guide pin 102 is anchored in the upper end portion 60

or 64 of one of the elongate bars 52, 54, such as the rear bar 54, and extends transversely toward the upper end portion of the other elongate bar, such as the front bar 52. The guide bore 104 is formed through the upper end portion of the other of the elongate bars, such as the front bar 52 for slidably receiving the guide pin 96 therethrough as the bars 52, 54 are pivotally moved relative to one another.

The limit means 92, being a set screw threadably received through the upper end portion of one of the elongate bars, such as the front bar 52, extends transversely toward the upper end portion of the other of the elongate bars, such as the rear bar 54 for engagement therewith upon relative pivotal movement of the bars toward one another. The set screw 92 is adjustable for presetting the minimum displacement between the upper end portions 60, 64 of the elongate bars 52, 54 and thereby defining a maximum force which can be applied at their lower end portions 62, 66 to the resilient spring 44 in the grid cell 42.

Finally, the grid force measuring apparatus 50 includes means for sensing and recording the spring force of the grid cell 42. First, means in the form of a strain gauge 106 is attached to the lower end portion of one of the elongate bars, such as the front bar 52, a short distance below its mid-section 56. The strain gauge 106 senses the level of the increasing force being applied to the spring 44 within the one grid cell 42 into which the bars 52, 54 are inserted. Although the bars 52, 54 are made of metal, the lower end portion 62 of the front bar 52 is thin enough in cross-section so as to have sufficient flexure to give a meaningful strain gauge readout.

Also, the measuring apparatus 50 has means, generally designated 108, in the form of a pair of electrical contacts being coupled between the lower end portions 62, 66 of the front and rear bars 52, 53 and capable of breaking contact with one another when application of

the increasing force to the spring 44 in the cell 42 causes deflection of the spring to occur. The pair of electrical contacts 108 includes a circuit element in the form of an electrically conducting plate 110 attached to and electrically insulated from the lower end portion of one of the elongate bars, such as the front bar 52, and the set screw 86 attached to the lower end portion of the other of the elongate bars, such as the rear bar 54. As mentioned earlier, one function of the set screw 86 is to preset the displacement between the lower end portions 62, 66 of the elongate bars 52, 54. The second function is to provide electrical contact with the circuit element 110 when the elongate bars 52, 54 are initially inserted into the grid cell 42.

Lastly, as seen in Fig. 7, the measuring apparatus 50 has means in the form of a readout 112, preferably a suitable digital type, coupled across the terminals 114, 116 of the strain gauge 106, being preferably in a bridge arrangement, and in parallel with the contacts 108. The readout 112 indicates the level of force at the instance deflection of the spring 44 occurs. Specifically, a pair of lead lines 118, 120 couples the readout in series with the strain gauge terminals 114, 116. However, the contacts 108, i.e., the circuit element 110 and set screw 86, are also connected by lead lines 122, 124 in series with the strain gauge terminals. When the contacts 108 are closed, the terminals 114, 116 of the strain gauge 106 are effectively short circuited and no force level signal is conducted to the readout 112. However, when the force applied to the grid cell spring 44 is marginally greater than the spring force, the spring 44 deflects and the electrical contacts 108 go from a closed to an open condition. Then the strain gauge terminals 114, 116 are no longer shorted and a signal is generated by the strain gauge 106 and received and recorded by the readout 112 at the instance the contacts 108 are opened. This provides a determination

of the spring force for the preselected fuel rod 18 outside diameter.

In Fig. 7, the pivotally connected elongate bars 52, 54 of the measuring apparatus 50 are shown placed vertically in the grid cell 42 to be measured, with the rear bar 54 in contact with both grid dimples 46 and the front bar 52 in contact with the grid spring 44. With the bars preset by the set screw 86 at the selected fuel rod outside diameter dimension and rotatable shaft 82 in a loosened condition, the depth of insertion into the grid cell is preset by the adjustable positioning stop 88. By turning the knob 84, the shaft 82 is gradually tightened until electrical contact between the set screw 86 and the insulated conducting circuit element 110 is broken. The contact break is monitored electrically such that at the instance the break occurs, the strain gauge 106 reading is recorded by readout 112. This reading determines the spring force for one spring 44 and its associated pair of dimples 46 at the preset dimension across the bars 52, 54. The same steps are repeated to measure the spring force for the other spring and pair of dimples in the same cell. The two readings are added together to get the total spring force in the given cell.

By increasing or decreasing the preset dimension between the bars 52, 54 by, for example, increments of two thousandths of one inch, the bars may be reinserted into the cell 42 and the spring force again determined. Using differences in spring force for the incremental changes in preset dimensions, the spring rate characteristic of th cell can be derived over the total required range.

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CLAIMS:

1. A spring-force measuring apparatus for measuring the spring force imposed on a fuel rod when inserted through a cell in a support grid of a fuel assembly which cell contains fuel-rod supporting spring means, characterized by the combination comprising:

(a) means (80) for generating an increasing force at a first location external of said grid cell (42);

(b) means (52, 54, 86) for transmitting said increasing force from said first location and applying said increasing force to said spring means (44) within the cell (42); and

(c) means (106, 108, 112) for measuring the level of said increasing force at the instance the application of said force causes deflection of said spring means (44).

2. A spring-force measuring apparatus according to claim 1, characterized in that said increasing force is applied to said spring means at said second location in a direction generally perpendicular to a central axis of the grid cell along which said fuel rod is inserted through said cell.

3. A spring-force measuring apparatus according to claim 1 or 2, characterized in that the force transmitting and applying means (52, 54, 86) comprises a pair of elongate members (52, 54) each having a mid-section (56, 58) and first and second end portions (60, 62; 64, 66) extending from the mid-section in opposite directions, said

elongate members (52, 54) being pivotally connected together at the mid-sections thereof, their first end portions (60, 64) extending in substantially parallel spaced relationship with respect to each other, and their second end portions (62, 66) extending in substantially parallel spaced relationship adjacent each other, said second end portions (62, 66) of the two elongate members having dimensions such as to be insertable together into any one of the grid cells (42), and said first end portions (60, 64) being operable to gradually vary the spacing between said second end portions.

4. A spring-force measuring apparatus according to claim 3, characterized in that said elongate members (52, 54) are bars pivotally connected together in a manner such that movement of said first end portions (60, 64) toward and away from one another effects movement of said second end portions (62, 66) away from and toward each other, respectively, the first and second end portions (60, 62) of one (52) of the elongate members being offset with respect to each other in the direction perpendicular to the other elongate member (54).

5. A spring-force measuring apparatus according to claim 3 or 4, characterized in that said force transmitting and applying means (82, 54, 86) includes an adjustable means (86) disposed on the second end portion of one (54) of said elongate members and cooperable with the second end portion of the other elongate member (52) to preset a minimum spacing between said lower end portions (62, 66) and thereby a minimum combined cross-sectional dimension thereof such that, when inserted into a grid cell (42), said lower end portions (62, 66) of the elongate members (52, 54) simulate a fuel rod (18) having a predetermined outer diameter.

6. A spring-force measuring apparatus according to claim 3, 4 or 5, characterized in that the force generating means (80) comprises a member (82) operatively engaged with said first end portions (60, 64) of the

elongate members (52, 54) and operable to apply thereto a force transmitted through the elongate members to said second end portions (62, 66) thereof and applied by the latter, when inserted in a grid cell (42), to the spring means (44) therein.

7. A spring-force measuring apparatus according to claim 6, characterized in that said member (82) comprises a shaft (82) rotatably connected to the first end portion of one (52) of said elongate member and threadably engaged with the first end portion of the other elongate member (54).

8. A spring-force measuring apparatus according to claim 7, characterized in that said member (82) includes a knob (84) connected to one end of said shaft (82) to facilitate rotation of the latter.

9. A spring-force measuring apparatus according to any one of the claims 3 to 8, characterized in that one of said elongate members (52, 54) has disposed thereon an adjustable stop (88) adapted, upon insertion of said second end portions (62, 66) of the elongate members into a cell (42) of the grid (16), to engage the grid and thereby properly position said second end portions in force-applying relation with respect to the spring means (44) disposed in the cell.

10. A spring-force measuring apparatus according to any one of the claims 3 to 9, characterized in that said elongate members (52, 54) have associated therewith guide means (90) cooperating with said first end portions (60, 64) thereof so as to assist in maintaining alignment of the elongate members with one another during pivotal movement thereof relative to each other.

11. A spring-force measuring apparatus according to claim 10, characterized in that said guide means (90) comprises a guide pin (102) secured to the first end portion of one (54) of the elongate members (52, 54), and a guide hole (104) formed in the first end portion of the

other elongate member (52) and having said guide pin (102) slidably engaged therein.

12. A spring-force measuring apparatus according to any one of the claims 3 to 11, characterized in that one (52) of said elongate members (52, 54) has disposed on said first end portion thereof a limit means (92) cooperating with the first end portion of the other elongate member (54) in a manner which limits such relative pivotal movement of the elongate members with respect to each other as results in increasing the spacing between the second end portions (62, 66) of the elongate member, and which thus limits the maximum force applicable by said second end portions to said spring means (44), said limit means (92) being adjustable.

13. A spring-force measuring apparatus according to claim 12, characterized in that said limit means (92) is a set screw threadedly engaged with the first end portion of said one elongate member (52) and engageable with the first end portion of said other elongate member (54).

14. A spring-form measuring apparatus according to any one of claims 3 to 13, characterized in that said measuring means (106, 108, 112) comprises force-sensing means (106) connected to at least one of said elongate members (52, 54) for sensing the level of increasing force applied through said second end portions of the elongate members to said spring means (44); deflection sensing means (108) connected to at least one of said elongate members (52, 54) for sensing when deflection of said spring means (44) occurs during application of said increasing force, and indicating means (112) connected to said force sensing means (106) and said deflection sensing means (108) for indicating the level of force applied at the instance said deflection of the spring means (44) is occurring.

15. A spring-force measuring apparatus according to claim 14, characterized in that said force sensing means (106) is a strain gauge (106) connected to said second end portion of one (52) of the elongate members (52, 54).

16. A spring-force measuring apparatus according to claim 14 or 15, characterized in that said deflection sensing means (108) comprises a pair of normally closed electrical contacts connected between said second end portions (62, 66) of the elongate members (52, 54) and adapted to open upon initial deflection of said spring means (44) resulting from application of said increasing force.

17. A spring-force measuring apparatus according to claim 16, characterized in that said pair of electrical contacts (108) comprises a first conduction element (110) disposed on and electrically insulated from the second end portion of one of said elongate members (52, 54), and a second conduction element (86) disposed on the second end portion of the other elongate member, said second conduction element comprising an adjustable set screw disposed in contact with said first conduction element (110) when the second end portion of the elongate members (52, 54) are initially inserted into a grid cell (42).

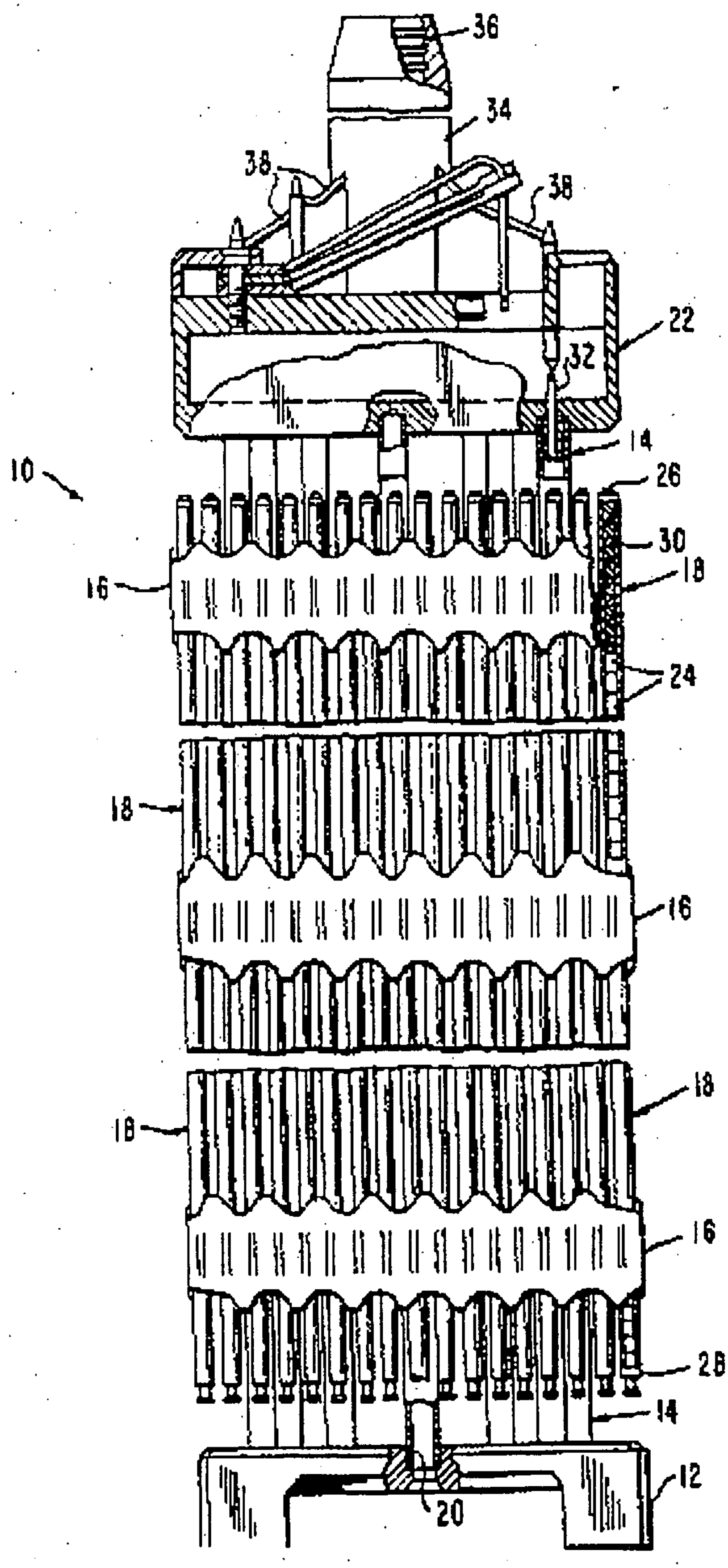


Fig. 1

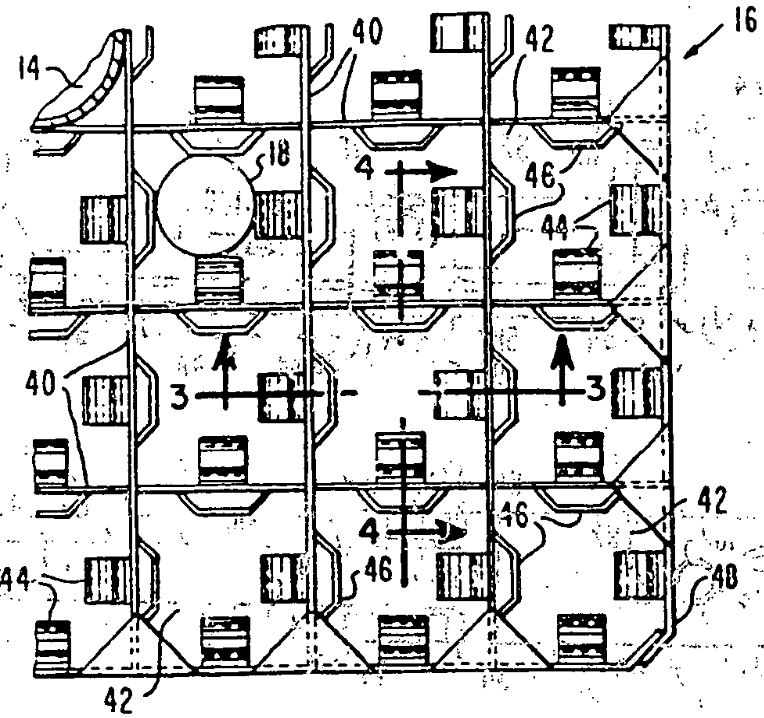


Fig.2

Fig.3

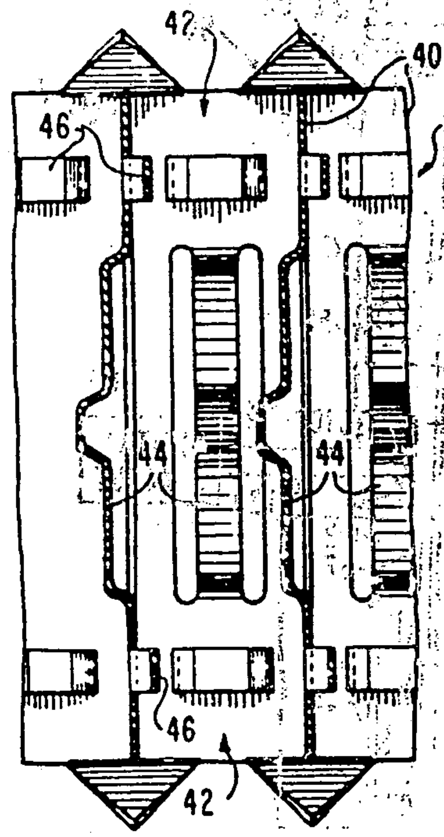
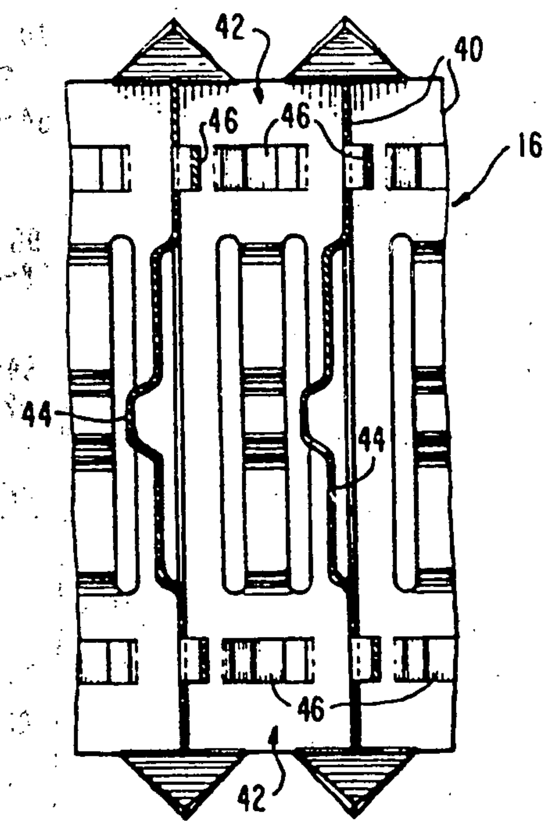


Fig.4



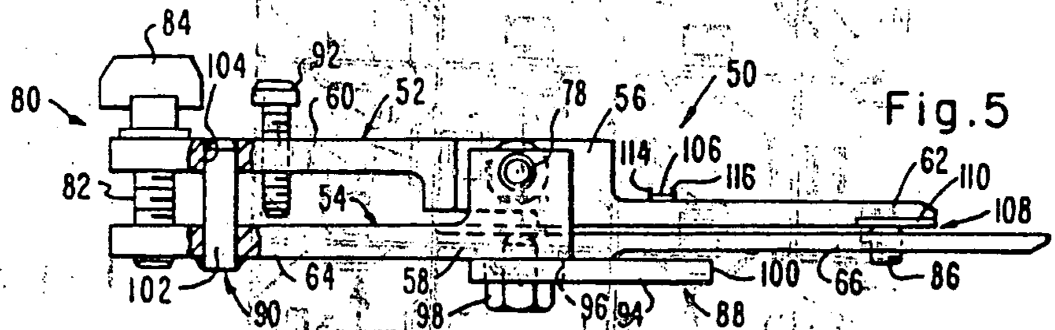


Fig.5

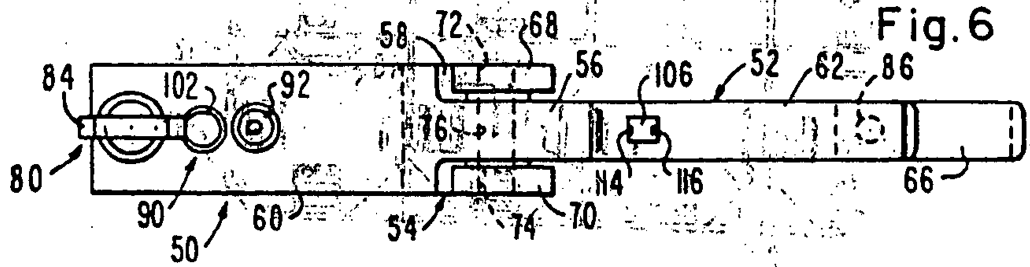


Fig.6

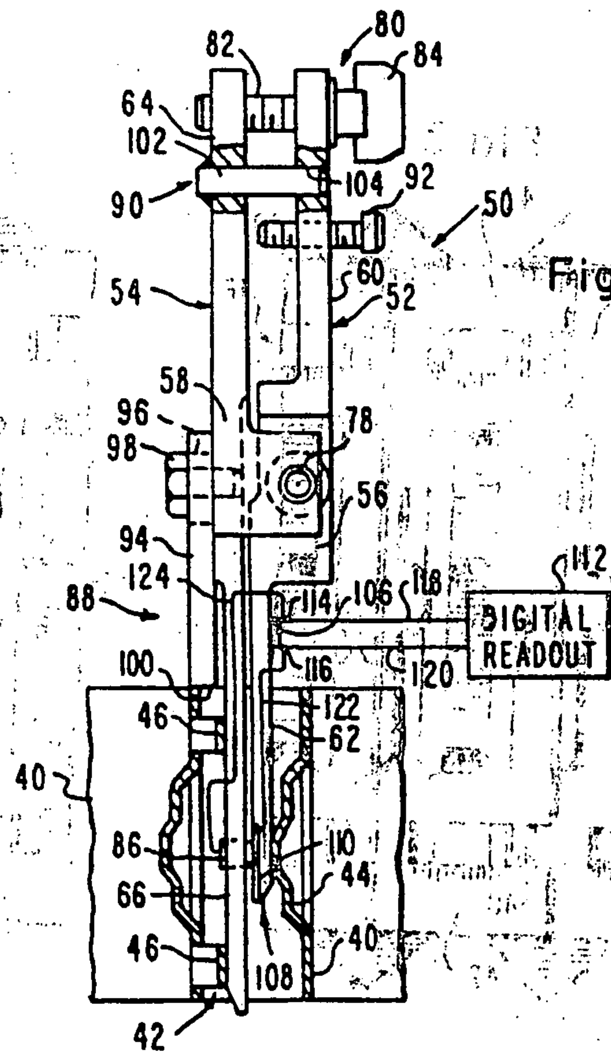


Fig.7